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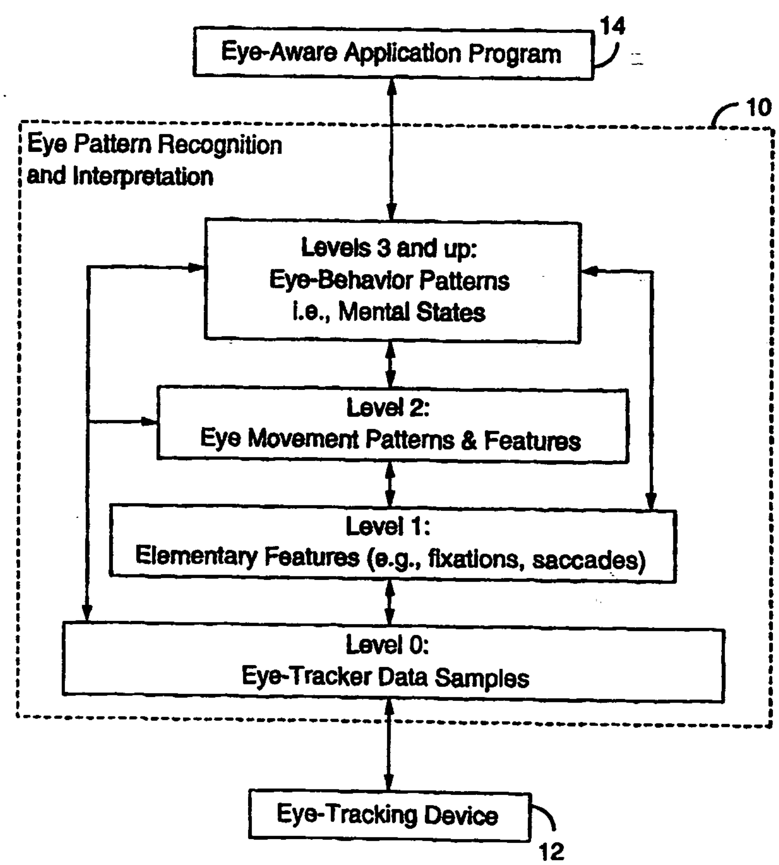
(54) Title: METHOD FOR INFERRING MENTAL STATES FROM EYE MOVEMENTS

(57) Abstract

A computer implemented method (10, 14) infers mental states of a person from eye movement of the person. The method includes identifying elementary features of eye tracker data, such as fixations and saccade, and recognizing from the elementary features a plurality of eye movement patterns. Each eye movement pattern is recognized by comparing the elementary features (10) with a predetermined eye movement pattern template. A given eye movement pattern is recognized if the elementary features satisfy a set of criteria associated with the template for that eye movement pattern. The method further includes the step of recognizing from eye movement patterns a plurality of eye behaviour patterns corresponding to the mental states of the person. Because high level mental states of the user are determined in real time, the method provides the basis for reliably determining when a user intends to select a target.



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Method for Inferring Mental States from Eye Movements

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from US provisional application 60/062,178 filed October 16, 1997, which is hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates generally to the field of eye tracking and methods for processing eye tracking data. In particular, the invention relates to a system and method for determining mental states or mental activities of a person from spatio-temporal eye-tracking data, independent of a priori knowledge of the objects in the person's visual field.

BACKGROUND

In recent years, eye-tracking devices have made it possible for machines to automatically observe and record detailed eye movements. One common type of eye tracker, for example, uses an infrared light-source, a camera, and a data processor to measure eye gaze positions, i.e. positions in the visual field at which the eye gaze is directed. The tracker generates a continuous stream of spatiotemporal data representative of eye gaze positions at sequential moments in time. Analysis of this raw data typically reveals a series of eye fixations separated by sudden jumps between fixations, called saccades.

An informative survey of the current state of the art in the eyetracking field is given in Jacob, R. J. K., "Eye tracking in advanced interface design", in W. Barfield and T. Furness (eds.), *Advanced interface design and virtual environments*, Oxford University Press, Oxford, 1995. In this article, Jacob describes techniques for recognizing fixations and saccades from the raw eye tracker data, but fails to teach any specific methods for recognizing a user's conscious intentions or mental states. Fixation and saccade data alone, however, is still relatively low-level data that is of limited use. These eye tracking methods, therefore, still fall short of the goal of providing useful information about any higher-level eye behavior or mental states.

One attempt to derive higher-level cognitive information from eye movement data is described by India Starker and Richard A. Bolt in "*A gaze-responsive self-disclosing display*", *CHI '90 Proceedings*, April 1990. Their technique correlates eye fixation data with a priori knowledge of objects in the user's field of view (i.e., on the computer screen) to make inferences about the degree of interest the user has in each object. One major disadvantage of this technique is that it requires a priori knowledge of the objects in the user's visual field, such as their positions, shapes and type information. Consequently, the technique cannot be used in many computer software applications where information about what is displayed on a computer screen is not readily available. In addition, it cannot be used in other situations where a priori knowledge is not available, such as when the user is not viewing virtual objects on a computer screen, but physical objects in the real world.

In addition, because the technique disclosed by Starker and Bolt identifies the attention of the user with single fixation points, it fails to accurately distinguish the attentively looking at an object from inattentively "spacing out" while gazing at the object. Thus, although the technique attempts to recognize the high-level state of attentive interest, it actually fails to properly distinguish this state from non-attentiveness. It will also be noted that Starker and Bolt propose a technique that is limited to identifying just one cognitive state.

SUMMARY

In view of the above, it is an object of the present invention to overcome the disadvantages and limitations of existing methods for deriving useful information from eye tracker data. In particular, it is an object of the present invention to provide a method for accurately recognizing a variety of high-level mental states of a user from eye tracker data. It is another object of the invention to provide such a technique that does not require a priori information about objects in the user's visual field, and is not limited to situations where the user is looking at a computer screen.

These and other objects and advantages are provided by a computer-implemented method for inferring mental states of a person from eye movements of the person. The method includes identifying elementary features of eye tracker data, such as fixations, saccades, and smooth pursuit motion. Identifying a fixation typically includes identifying a fixation location and a fixation duration. Identifying a saccade typically involves identifying a

beginning and end location of the eye-movement, as well as possibly determining the velocity and other characteristics of the movement. It will be noted that for many applications that do not consider the velocity of the saccade, identifying two successive fixations can be used to identify a saccade. Identifying smooth pursuit motion typically includes identifying the velocity and path the eye takes as it smoothly follows a moving object. The method also includes recognizing from the elementary features a plurality of eye-movement patterns, i.e., specific spatiotemporal patterns of fixations, saccades, and/or other elementary features derived from eye tracker data. Each eye-movement pattern is recognized by comparing the elementary features with a predetermined eye-movement pattern template. A given eye-movement pattern is recognized if the features satisfy a set of criteria associated with the template for that eye-movement pattern. The method further includes the step of recognizing from the eye-movement patterns a plurality of eye-behavior patterns corresponding to the mental states of the person.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of central components in a preferred embodiment of the present invention and their relationships.

FIGS. 2A-2C are graphical illustrations of three eye movement patterns according to the present invention.

FIGS. 3A-3D are graphical illustrations of four higher level eye behavior patterns according to the present invention.

DETAILED DESCRIPTION

In a preferred embodiment of the present invention, raw data samples representative of eye gaze positions are communicated to a microprocessor 10 from a conventional eye tracking device 12, as illustrated in FIG. 1. Any method for measuring eye position or movement, whether optical, electrical, magnetic, or otherwise, may be used with the present invention. A method of eye pattern recognition and interpretation implemented on the microprocessor processes and analyzes the raw data samples to produce in real time a series of eye behavior patterns which correspond to high level mental states or activities. This high level information is then typically made available to an application program 14 which uses the information to perform application-specific tasks. A few of the many examples of application programs which will benefit from the high level eye pattern information provided by the methods of the present invention are: an on-screen keyboard for the disabled, an eye-controlled pointing device, reading instructional software, an experimental tool in psychological research, an eye-aware web browser, and a user interface for rapid navigation of hierarchical information. The methods of the present invention, however, do not depend on the use of any particular application. In fact, it is a key feature of the present invention that it provides application-independent eye pattern recognition and interpretation. Moreover, the present invention provides for the first time the ability to accurately recognize high-level eye behavior patterns independent of any a priori knowledge of the content of the user's visual field or other contextual information. Provided suitable eye position data is available, the present invention is even able to recognize eye patterns and mental states of a person who is dreaming or mentally disengaged from the external world in other ways.

In accordance with the teachings of the present invention, eye pattern recognition and interpretation is performed by a collection of hierarchical levels of data interpretation. As illustrated in FIG. 1 and in TABLE I, the fundamental level of data is LEVEL 0, which corresponds to the raw, uninterpreted eye-tracker data samples. The first level of interpretation, LEVEL 1, involves identifying elementary features such as fixations and saccades from the raw data provided by LEVEL 0. It is at this primitive level of interpretation that prior methods end. The present invention, in contrast, provides additional higher-level interpretations of the data. In particular, LEVEL 2 interpretation involves identifying from the fixations and saccades eye-movement patterns, typically consisting of a set of several fixations and/or saccades satisfying certain predetermined criteria. LEVEL 3 interpretation, in turn, involves identifying from the LEVEL 2 eye movement patterns various eye-behavior patterns. These eye-behavior patterns typically consist of various movement patterns satisfying particular criteria. Additional levels may provide higher levels of interpretation that build on previous levels. The highest interpretive levels correspond with mental states of the user. For the purposes of this description, a mental state of the user includes mental activities, mental intentions, mental states, and other forms of cognition, whether conscious or unconscious.

TABLE I

Interpretive Level	Description
LEVELS 3 and up	EYE-BEHAVIOR PATTERNS <=> MENTAL STATES

LEVEL 2	EYE-MOVEMENT PATTERNS
LEVEL 1	ELEMENTARY FEATURES: FIXATIONS/SACCADES
LEVEL 0	EYE-TRACKER DATA SAMPLES

It will be noted, as indicated in FIG. 1, that higher levels of interpretation can make use of interpretive data on more than one lower level. For example, although LEVEL 3 interpretation is based primarily upon the results of LEVEL 2 interpretation, it may also make use of LEVEL 1 fixation and saccade information, or even LEVEL 0 raw data if necessary. It should also be noted that information in higher levels of the hierarchy can be provided to lower levels for various useful purposes. For example, criteria for recognizing fixations during LEVEL 1 interpretation can be adjusted in dependence upon the current mental state derived from LEVEL 3 interpretation. This feature permits the system to be dynamically and intelligently adaptive to different users as well as to different mental states of a single user.

We now turn to a more detailed discussion of the various levels of interpretation mentioned above. TABLE II below lists the typical information present at LEVEL 0. Commonly available eye tracker devices generate a data stream of 10 to 250 position samples per second. In the case of monocular eye trackers, the z component of the gaze position is not present. Eye trackers are also available that can measure pupil diameter. These pupil measurements provide additional information that can be useful at various levels of interpretation (e.g., pupil constriction during fixation can be used to refine selection). The data stream is preferably analyzed in real time by a LEVEL 1 interpretation procedure. The data

stream may also be stored in a memory buffer for subsequent analysis.

TABLE II

LEVEL 0: EYE TRACKER DATA SAMPLES
eye position (x,y,z)
sample time (t)
pupil diameter (d)
eye is opened or closed (percentage)

The LEVEL 1 interpretation procedure identifies elementary features of the eye data from the LEVEL 0 eye tracker data. As indicated in TABLE III, these elementary features include fixations and saccades. FIG. 2A is a graphical illustration of a sequence of fixations and saccades, with the fixations represented as solid dots and the saccades represented by directed line segments between the dots. Many techniques for identifying and recognizing fixations and saccades from eye tracker data are well-known in the art. It will be appreciated that LEVEL 1 interpretation may also identify other elementary features of the LEVEL 0 data, such as smooth pursuit motion. These features are stored in a memory buffer allocated for LEVEL 1 data.

TABLE III

LEVEL 1: ELEMENTARY FEATURES: FIXATIONS and SACCADES	
Elementary Feature	Feature Attributes
Fixation	Position, time, duration
Saccade	Magnitude, direction, velocity
Smooth Pursuit	Path taken by eye, velocity

Motion	
Blinks	Duration

Identifying a fixation typically involves identifying a fixation location and a fixation duration. For many purposes a saccade can be treated as simply the displacement magnitude and direction between successive fixations, though the changes in velocity do contain information useful for understanding the eye movement more specifically. The saccades may be explicitly identified and entered in the LEVEL 1 memory buffer, or may remain implicit in the fixation information stored in the buffer. Conversely, it will be appreciated that saccade information implicitly contains the relative positions of fixations.

The elementary features, such as saccades, fixations, smooth pursuit motion and blinks, now form the basis for further higher level interpretation. This LEVEL 2 interpretation involves recognizing eye-movement patterns. An eye movement pattern is a collection of several elementary features that satisfies a set of criteria associated with a predetermined eye-movement pattern template. As shown in TABLE IV below, various eye-movement patterns can be recognized at this level of interpretation. Typically, in practice, after each saccade the data is examined to check if it satisfies the criteria for each of the movement patterns.

TABLE IV

LEVEL 2: EYE-MOVEMENT PATTERN TEMPLATES	
Pattern	Criteria

Revisit	The current fixation is within 1.2 degrees of one of the last five fixations, excluding the fixation immediately prior to the current one
Significant Fixation	A fixation of significantly longer duration when compared to other fixations in the same category
Vertical Saccade	Saccade Y displacement is more than twice saccade X displacement, and X displacement is less than 1 degree
Horizontal Saccade	Saccade X displacement is more than twice saccade Y displacement, and Y displacement is less than 1 degree
Short Saccade Run	A sequence of short saccades collectively spanning a distance of greater than 4 degrees
Selection Allowed	Fixation is presently contained within a region that is known to be selectable

If LEVEL 1 data fits one of the LEVEL 2 eye-movement pattern templates, then that pattern is recognized and a pattern match activation value is determined and stored in a LEVEL 2 memory buffer. The pattern match activation value can be an on/off flag, or a percentage value indicating a degree of match. It should be noted that some LEVEL 2 patterns may have criteria based on LEVEL 0 data, or other LEVEL 2 data. Normally, however, LEVEL 2 pattern templates have criteria based primarily on LEVEL 1 information. It should also be noted that the eye-movement patterns are not mutually exclusive, i.e., the same LEVEL 1 data can simultaneously

satisfy the criteria for more than one eye-movement pattern template. This "pandemonium model" approach tolerates ambiguities at lower levels of interpretation, and allows higher levels of interpretation to take greater advantage of the all the information present in the lower levels.

In addition to recognizing patterns, LEVEL 2 interpretation also may include the initial computation of various higher level features of the data. These LEVEL 2 features and their attributes are shown in TABLE V below. In the preferred embodiment, the term "short saccade" means a saccade of magnitude less than 3 degrees, while the term "long saccade" means a saccade of magnitude at least 3 degrees. It will be appreciated, however, that this precise value is an adjustable parameter.

TABLE V

LEVEL 2: EYE-MOVEMENT FEATURES	
Feature	Attributes
Saccade Count	Number of saccades since the last significant fixation or last identification of higher level pattern
Large Saccade Count	Number of large saccades since the last significant fixation or last identification of higher level pattern

These features are used in the interpretation process in LEVEL 2 and higher levels. The movement patterns recognized on LEVEL 2 are also used to recognize other movement patterns, as well as behavior patterns on higher levels. For example, revisits can be

used to determine when a user has found a target after searching. Significant fixations, i.e., fixations whose duration are abnormally long, tend to convey information about the change in user state. Examining the length of sequences of saccades can provide information regarding the mental activity of the user. For example, consider the fact that a person can clearly perceive the area around a spot where a significant fixation occurred. Thus, if the user makes a small saccade from that spot, then the user is making a knowledgeable movement because he is moving into an area visible through peripheral vision. If the user makes a short saccade run, as illustrated in FIG. 2A, the user is looking for an object locally. If, on the other hand, the user makes a large saccade after a significant fixation, followed by one or two small saccades, as illustrated in FIG. 2C, then this represents knowledgeable movement to a remembered location. This pattern of moving with knowledge is normally considered to hold until a different pattern is identified from further data. For example, multiple large saccades, illustrated in FIG. 2B, can indicate a pattern of global searching, which normally happens when the user is searching a large area for a target.

During searching, a fixation that is a revisit is treated as being in the knowledgeable movement category as long as that fixation lasts. This covers the situation when a user is searching, briefly perceives the desired target, moves to a new location before realizing that he just passed the desired target, and then moves back to (i.e., revisits) the previous fixation. Recognizing revisits makes it possible to transition back to knowledgeable movement after a user has been searching. It is relatively easy to recognize when a user has begun searching. This technique

makes it possible to make the more difficult recognition of when the user has stopped searching.

The eye movement patterns and features of LEVEL 2 form the basis for recognizing higher level eye behavior patterns during the LEVEL 3 interpretation. An eye behavior pattern is a collection of several eye movement patterns that satisfies a set of criteria associated with a predetermined eye-behavior pattern template. TABLE VI lists examples of common eye-behavior patterns. As with the previous level, these patterns are not necessarily mutually exclusive, allowing yet higher levels of interpretation, or an application program, to resolve any ambiguities. It will be appreciated that many other behavior patterns may be defined in addition to those listed below.

TABLE VI

LEVELS 3 and up: EYE-BEHAVIOR PATTERN TEMPLATES	
Pattern	Criteria
Best Fit Line (to the Left or Right)	A sequence of at least two horizontal saccades to the left or right.
Reading	Best Fit Line to Right or Short Horizontal Saccade while current state is reading
Reading a Block	A sequence of best fit lines to the right separated by large saccades to the left, where the best fit lines are regularly spaced in a downward sequence and (typically) have similar lengths
Re-Reading	Reading in a previously read area

Scanning or Skimming	A sequence of best fit lines to the right joined by large saccades with a downward component, where the best fit lines are not regularly spaced or of equal length
Thinking	several long fixations, separated by short spurts of saccades
Spacing Out	several long fixations, separated by short spurts of saccades, continuing over a long period of time
Searching	A Short Saccade Run, Multiple Large Saccades, or many saccades since the last Significant Fixation or change in user state
Re-acquaintance	Like searching, but with longer fixations and consistent rhythm
Intention to Select	"selection allowed" flag is active and searching is active and current fixation is significant

FIG. 3A illustrates an example of a sequence of several horizontal short saccades to the right, a pattern that would be recognized as reading a line of text. A best fit line through the sequence is indicated in the figure by a dashed line. FIG. 3B illustrates an example of how the reading a line of text pattern may be used as a basis for recognizing a higher level pattern. In this case, a sequence of three best fit lines to the right are joined by large saccades to the left. The best fit lines are regularly spaced in a downward sequence and have similar lengths, reflecting the margins of the text. This higher level pattern represents reading

a block of text. FIG. 3C illustrates how keeping track of the right and left margins (indicated by dashed vertical lines) while reading lines of text (indicated by rectangles) can be used to recognize when the text flows around a picture or other graphical object. FIG. 3D illustrates a high level pattern corresponding to scanning or skimming a page of text.

These examples illustrate how higher level cognitive patterns can be recognized from lower level eye movement patterns. It should also be noted that some LEVEL 3 behavior patterns are more introverted (e.g., spacing out) while others are more extroverted (e.g., reading or searching). Therefore, a mental introversion pattern can be recognized by testing for a shift from more extroverted behavior patterns to more introverted behavior patterns. Other cognitive patterns can similarly be defined and recognized. For example, the level of knowledge of the user can be determined by observing the number of transitions between behaviors in a given time period. There is no theoretical limit to the number of patterns or interpretive levels that may be introduced and implemented in accordance with the principles of the present invention.

It should be understood that the distinctions between the interpretive levels may be redefined or moved in various ways without altering the nature of the invention. In particular, patterns on one level may be considered to reside on another level than has been shown above. For example, searching may be considered to be a LEVEL 4 behavior pattern rather than a LEVEL 3 movement pattern. Even when such changes are made, however, the hierarchical structure of levels of the interpretation process,

and the way in which a collection of recognized patterns on one level are used as the basis for recognizing patterns on a higher level remains unchanged.

It will be appreciated that because implementation of the present method on the hardware level is necessarily linear, the hierarchical nature of the pattern interpretation will be manifested as a repetition of various low-level interpretive processing steps which are used in higher-level recognition. Regardless of whether this repetition takes the form of a single set of instructions repeatedly executed or a series of similar instructions executed in sequence, the hierarchical interpretation technique is nevertheless present.

While the present invention enjoys the advantage that it provides high level recognition of mental states based on eye data alone, if contextual data such as information about the positions of objects on a computer screen is available, it can be used to supplement the eye data and improve performance. For example, if it is known that text is being displayed in a specific region of the screen, then this information can be used to more accurately determine from the eye data what behavior a user is engaged in while looking within that region. In addition, if it is known that a certain region is selectable, then this contextual information can be provided to the system to allow recognition of the behavior of intending to select a selectable item, as indicated by the "selection allowed" behavior pattern in TABLE IV.

The present invention also enjoys the advantage that high level behaviors can be used to assist in providing a behavioral context

in recognizing lower level patterns. For example, significant fixations are recognized using criteria that are automatically updated and selected according to current behavior. The user's fixation duration times are recorded and classified by type of behavior (e.g., searching, reading, looking at a picture, thinking, or knowledgeable movement). Typically, for a given behavior that allows selection, the distribution of fixations with respect to duration time has a first peak near a natural fixation duration value, and a second peak near a fixation duration value corresponding to fixations made with an intention to select. The significant fixation threshold is selected for a given behavior by choosing a threshold between these two peaks. The threshold values for the behaviors are updated on a regular basis and used to dynamically and adaptively adjust the significant fixation thresholds. For example, if a user's familiarity with the locations of selectable targets increases, the natural fixation times will decrease, causing the significant fixation threshold to be automatically set to a lower level. This automatic adaptation allows the user to more quickly make accurate selections. Alternatively, a user may wish to manually fix a specific set of threshold values for the duration of a session.

It should be noted that a user who is unfamiliar with the contents of a visual field will typically display lots of searching activity, while a user who is very familiar with the contents of a visual field will typically display lots of knowledgeable looking. Thus, a user's familiarity with the contents of the visual field can be estimated by measuring the ratio of the frequency of intentional fixations to the frequency of natural fixations.

The present invention has the highly advantageous feature that it overcomes the long-standing "Midas Touch" problem relating to selecting items on a computer screen using eye-tracking information. Because the technique provided by the present invention identifies various high level mental states, and adaptively adjusts significant fixation thresholds depending on specific attributes of fixation in the current mental state, false selections are not accidentally made while the person is not engaged in selection activities. For example, while currently recognizing a searching behavior, the system will tolerate longer fixations without selection than while recognizing knowledgeable movement. In short, the key to solving the Midas Touch problem is to adaptively adjust target selection criteria to the current mental state of the user. Because prior art techniques were not able to recognize various high level mental states, however, they had no basis for meaningfully adjusting selection criteria. Consequently, false selections were inevitably made in various behavioral contexts due to the use of inappropriate target selection criteria.

CLAIMS

What is claimed is:

1. A computer implemented method for inferring mental states of a person from eye movements of the person in real time, the method comprising:

a) identifying a plurality of elementary features of eye tracker data for the person;

b) recognizing from the elementary features a plurality of eye movement patterns wherein each pattern satisfies a set of predetermined eye movement pattern template criteria; and

c) recognizing from the eye movement patterns a plurality of eye-behavior patterns corresponding to mental states of the person.

2. The method of claim 1 further comprising classifying the elementary features according to associated eye-behavior patterns.

3. The method of claim 2 wherein recognizing the eye movement patterns comprises recognizing a significant fixation when a current fixation duration is longer than a significant fixation threshold for a current eye-behavior, where the threshold is calculated from recent fixation duration times classified by the current eye-behavior.

4. The method of claim 1 wherein the plurality of eye behavior patterns comprises at least three eye behavior patterns.

5. The method of claim 1 further comprising computing high level features from the elementary features.

6. The method of claim 1 wherein the elementary features comprise fixations and saccades.

7. The method of claim 1 wherein the eye behavior patterns comprise a pattern selected from the group consisting of reading patterns, spacing out patterns, and searching patterns.

8. The method of claim 1 wherein recognizing the eye behavior patterns comprises identifying a sequence of short saccades to the right.

9. The method of claim 1 wherein the recognizing eye behavior patterns and recognizing eye movement patterns is accomplished with no knowledge of contents of the person's visual field.

10. A computer implemented method for inferring mental states of a person from eye movements of the person, the method comprising:

a) identifying elementary features of eye tracker data for the person;

b) recognizing from the elementary features a hierarchy of patterns on various interpretive levels, wherein recognized patterns on higher levels are derived from recognized patterns on lower levels, wherein highest level recognized patterns correspond to mental states of the person.

11. The method of claim 10 wherein recognizing comprises recognizing from the elementary features low-level patterns and recognizing from the low-level patterns higher-level patterns.

12. The method of claim 10 further comprising classifying the elementary features according to associated highest level recognized patterns.

13. The method of claim 12 wherein recognizing the highest level recognized pattern comprises recognizing a significant fixation when a current fixation duration is longer than a significant fixation threshold for a current highest level recognized pattern, where the threshold is calculated from recent fixation duration times classified by the current highest level recognized pattern.

14. The method of claim 10 wherein the plurality of highest level recognized patterns comprises at least three highest level recognized patterns.

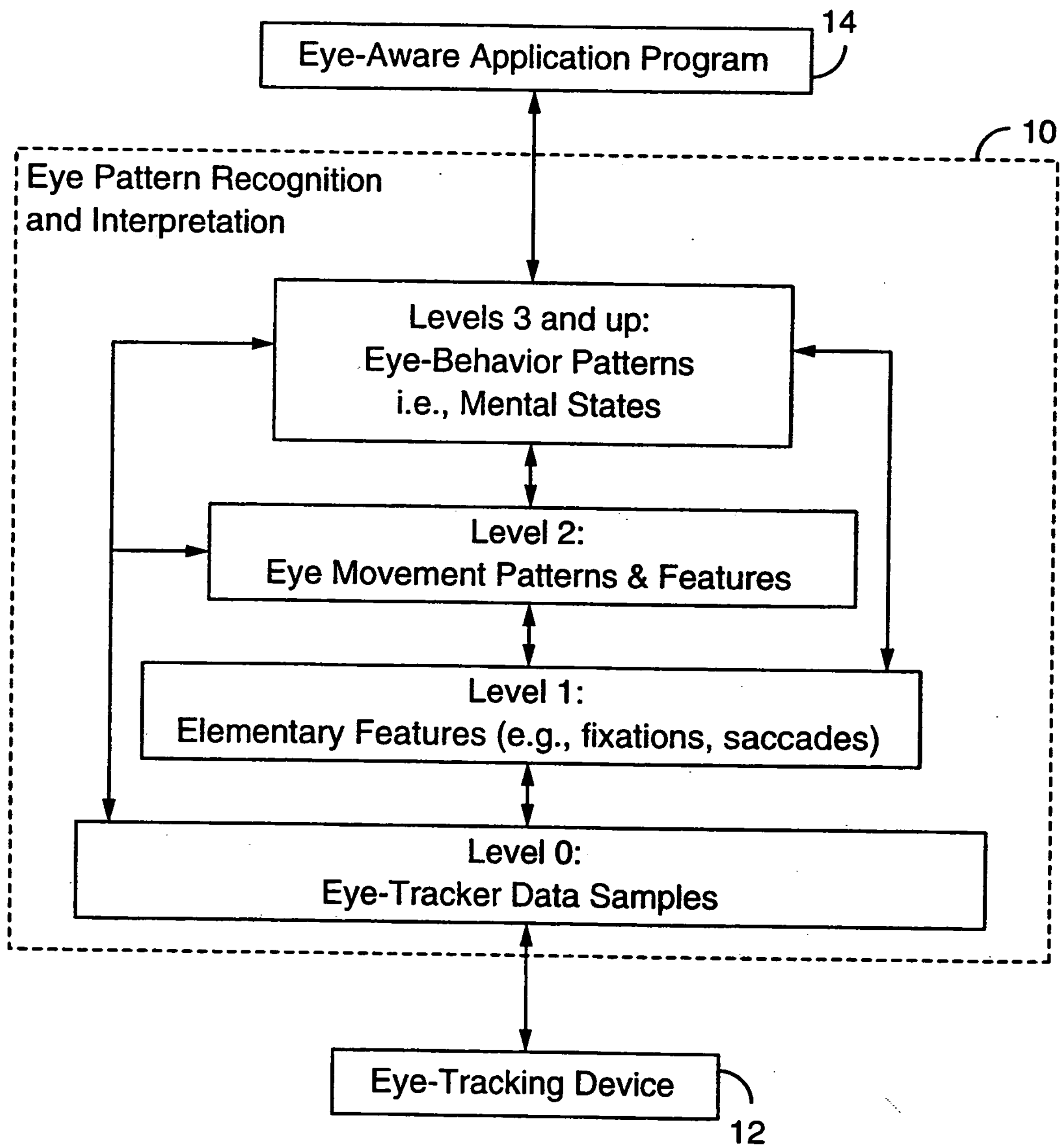
15. The method of claim 10 further comprising computing high level features from the elementary features.

16. The method of claim 10 wherein the elementary features comprise fixations and saccades.

17. The method of claim 10 wherein the highest level recognized patterns comprise a pattern selected from the group consisting of reading patterns, spacing out patterns, and searching patterns.

18. The method of claim 10 wherein recognizing the highest level recognized patterns comprises identifying a sequence of short saccades to the right.

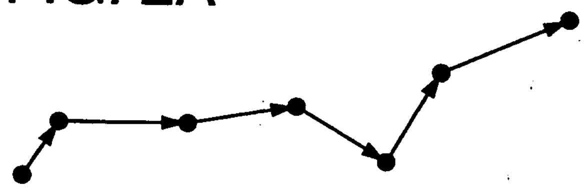
19. The method of claim 10 wherein the recognizing patterns on various interpretive levels and recognizing highest level patterns is accomplished with no knowledge of contents of the person's visual field.



Eye-Aware Application Program
14
10
Eye Pattern Recognition and Interpretation
Levels 3 and up: Eye-Behavior Patterns i.e., Mental States
Level 2: Eye Movement Patterns & Features
Level 1: Elementary Features (e.g., fixations, saccades)
Level 0: Eye-Tracker Data Samples
Eye-Tracking Device
12

FIG. 1

FIG. 2A



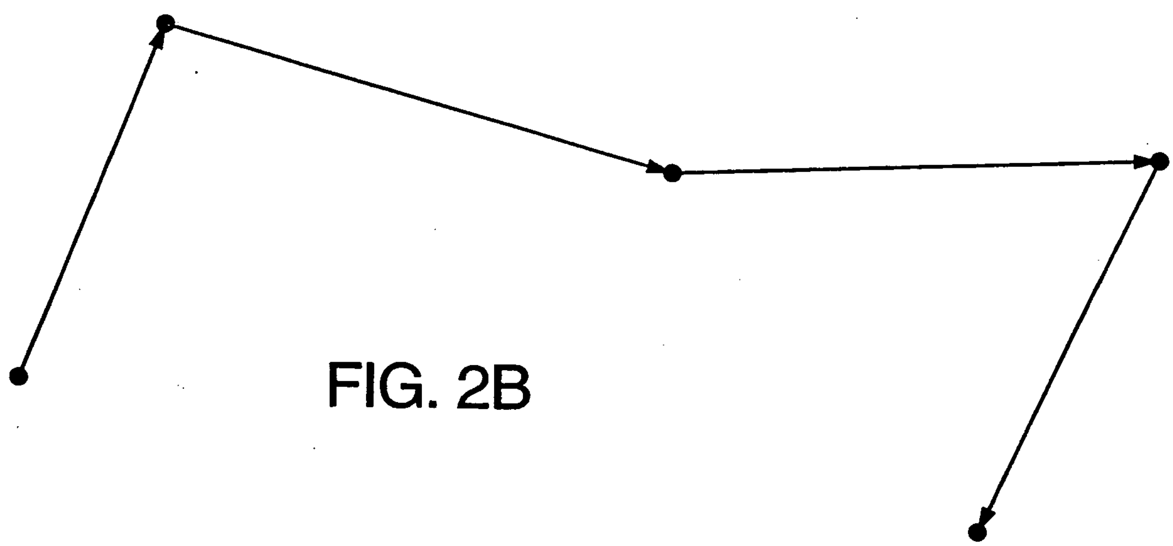


FIG. 2B

FIG. 2C

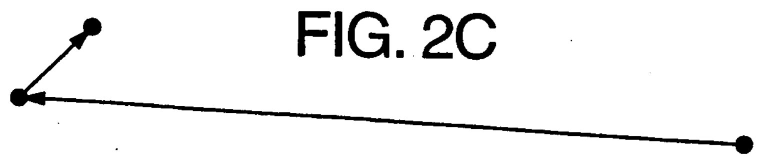


FIG. 3A

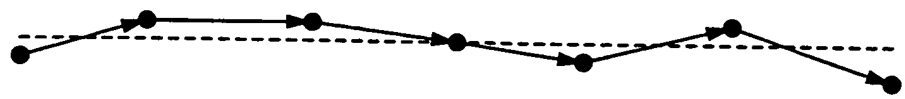


FIG. 3B

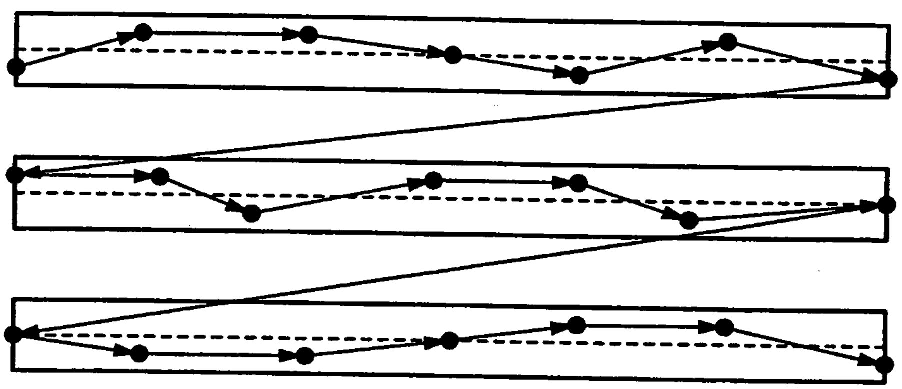


FIG. 3C

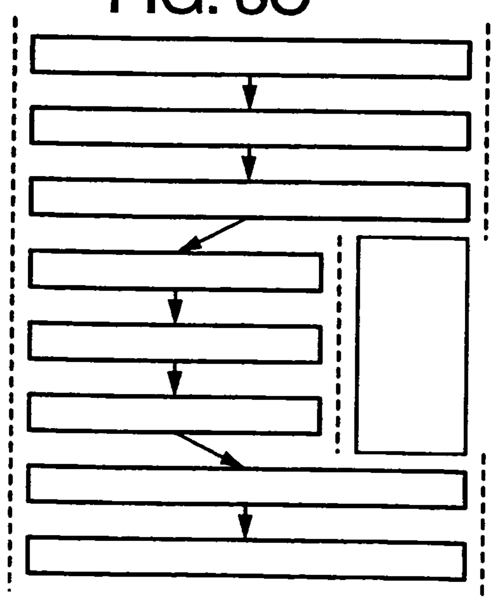
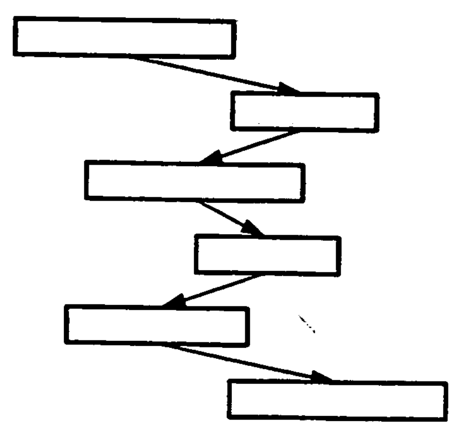


FIG. 3D



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/21816

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :A61B 3/14
US CL :351/209
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 351/205, 209, 210, 246; 434/236; 600/544, 545

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,280,793 A (ROSENFELD) 25 January 1994, entire document.	1-19
A	US 5,564,433 A (THORNTON) 15 October 1996, entire document.	1-19
A	US 3,691,652 A (CLYNES) 19 September 1972, entire document.	1-19

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier document published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search 14 JANUARY 1999	Date of mailing of the international search report 08 FEB 1999
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